CORE
Metadata, citation and similar papers at core.ac.uk
Provided by DigitalCommons@University of Nebraska

University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

Edward Schmidt Publications
Research Papers in Physics and Astronomy

4-2010

The Double-Mode Cepheid V371 Persei Redux

Edward G. Schmidt
University of Nebraska-Lincoln, eschmidt1@unl.edu

Follow this and additional works at: https://digitalcommons.unl.edu/physicsschmidt

Part of the Physics Commons

Schmidt, Edward G., "The Double-Mode Cepheid V371 Persei Redux" (2010). *Edward Schmidt Publications*. 51.
https://digitalcommons.unl.edu/physicsschmidt/51

This Article is brought to you for free and open access by the Research Papers in Physics and Astronomy at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Edward Schmidt Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, **123**:381–383, 2011 April
© 2011. The Astronomical Society of the Pacific. All rights reserved. Printed in U.S.A.

The Double-Mode Cepheid V371 Persei Redux

E. G. SCHMIDT[1]

Department of Physics and Astronomy, University of Nebraska-Lincoln, Lincoln, Nebraska 68502-0299; eschmidt1@unl.edu

Received 2010 December 16; accepted 2011 January 12; published 2011 February 24

ABSTRACT. A metallicity of $[\mathrm{Fe/H}] = -0.05$ to -0.40 was derived from four spectra of the peculiar beat Cepheid V371 Per. This conflicts with previous estimates ranging from -0.7 to -1.0 based on the period ratio. It is suggested that the discrepancy may be resolved by assuming near solar metallicity but a low mass. This is in accord with a suggestion by Sandage and Tammann that the AHB3 (or BL Her) stars are Population I analogs of short-period type II Cepheids. Further pulsational modeling is needed to clarify the status of this star and to understand the AHB3 stars.

1. INTRODUCTION

Schmidt et al. (1995) suggested that V371 Per was possibly a double-mode Cepheid based on the excess scatter in its light curve. Wils et al. (2010) followed up on this suggestion by obtaining further photometric observations and analyzing all the available data, nearly 3000 light-curve points spread over 17 yr. They verified that this star is indeed a double-mode pulsator with fundamental and first overtone periods of 1.738 days and 1.270 days. These periods are shorter and the period ratio, $P_1/P_0 = 0.731$, is larger than for any other known Galactic double-mode Cepheid. In fact, both of these quantities place this star among the double-mode Cepheids in the Small Magellanic Cloud (as shown in Fig. 6 of Wils et al. 2010). This suggests that the periods result from low metallicity, and a comparison with pulsational models gives [Fe/H] between -0.7 and -1.0.

Assuming a period-luminosity relation appropriate to a classical Cepheid, Wils et al. (2010) estimate that V371 Per is about 800 pc, roughly 10 classical Cepheid scale heights, from the Galactic plane. This would place it in the thick disk or halo. In spite of this and in spite of the low metallicity, Wils et al. (2010) present a variety of arguments indicating that it is a Population I Cepheid. If this is correct, V371 Per is arguably the only known Population I Cepheid in the Galaxy with such a low metallicity and at such a large distance from the Galactic plane.

Wils et al. (2010) suggest that this extraordinary object requires further investigation. The present article presents new spectral results that were obtained to verify the low metallicity.

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy under cooperative agreement with the National Science Foundation.

2. OBSERVATIONS AND ANALYSIS

Low-resolution spectra of V371 Per were obtained on four nights in 2009 January with the GoldCam spectrograph on the Kitt Peak 2.1 m telescope, and effective temperatures, gravities, metallicities, and color excesses were determined from them. The observations, reductions, and analyses were done together with the spectra discussed by Schmidt et al. (2011); that article should be consulted for details concerning the data and the procedures. The spectra are listed in Table 1, where each is identified by its Heliocentric Julian Date (HJD) in column (1).

The determination of the star's color at the epochs of our spectra is complicated by the double-mode behavior. To deal with this, we fitted a model for the $V - R$ color as a function of HJD that consisted of a sine and cosine term for each of the frequencies listed in Table 3 of Wils et al. (2010), as well as for twice the frequencies of the fundamental and first overtone. The photometry was taken from the sources listed in Table 1 of Wils et al. (2010). With a few unmatched magnitudes and outliers omitted, 2843 measured $V - B$ colors were included in the solution. The rms scatter of the data about the model was ± 0.019 mag. Since the photometry spanned just over 3600 fundamental cycles and our spectra were taken only 400 cycles after the end of the photometry, the extrapolation forward in time should introduce negligible error. The resulting colors are listed in column (2) of Table 1.

The effective temperatures, gravities, metallicities, and color excesses derived from the individual spectra are given in columns (3), (4), (5), and (6) of Table 1.

Also in Table 1, we list the means and standard deviations of the various parameters. The listed color is the intensity mean of the entire photometric data set. The individual effective temperatures were corrected to the mean color before averaging. This correction made only a modest difference; without it the mean was $\langle T_{\mathrm{eff}} \rangle = 6258 \pm 106$.

3. DISCUSSION

Wils et al. (2010) adopted a color excess for V371 Per of $E_{B-V} = 0.11$ based on the extinction maps of Schlegel et al. (1998). Our reddening of $E_{V-R} = 0.136$ corresponds to approximately $E_{B-V} = 0.22$ (using the reddening ratio from McCall 2004). This discrepancy is large, but could be due to patchy reddening that is not captured by the extinction maps. Wils et al. (2010) then derived a temperature from the color of no more than 6000 K, while our value is 6215 K. Comparison of our spectroscopic temperatures with previous values (Schmidt et al. 2011) suggested that they could be systematically too high by as much as 480 K. Thus, the temperature discrepancy is within the uncertainties.

The metallicities present a more serious difficulty. Wils et al. (2010) estimated that [Fe/H] was between -0.7 and -1.0 based on the Petersen diagrams of Buchler & Szabó (2007) and Buchler (2008) or -0.92 from the empirical relation of Sziládi et al. (2007). Our mean value of $[\mathrm{Fe/H}] = -0.05$ is much higher. Again, Schmidt et al. (2011) noted the possibility of a systematic error in the metallicity in the sense that our value could be too high by up to 0.35. This would bring the present estimate to $[\mathrm{Fe/H}] = -0.40$, still insufficient to reconcile the metallicity estimates.

The higher metallicity obtained here requires that we reconsider the earlier conclusions of Wils et al. (2010): in particular, the argument that V371 Per is a classical Cepheid of low metallicity.

An alternate explanation would be to assume that V371 Per is a BL Her star, albeit the only one that exhibits double-mode pulsation. Such stars often have metallicities close to solar (Harris 1981; Schmidt et al. 2011), similar to what we find for V371 Per. This also eliminates the difficulty of finding a classical Cepheid at a large distance from the Galactic plane.

Wils et al. (2010) argued that the light curve of V371 Per does not resemble the very asymmetric curves of the BL Her stars. However, Diethelm (1983) has shown several distinct types of light curves among short-period type II Cepheids. While the stars he refers to as RRd stars, illustrated in his Figure 1, do indeed exhibit a very steep rise from minimum, this is not the case with the BL Herculis stars shown in his Figure 3. For example, the light curve of V527 Sgr is rather similar in appearance to the prewhitened light curves of V371 Per shown in Figure 2 of Wils et al. (2010).

In a subsequent study, Diethelm (1983) changed the name of the BL Her stars to AHB3 and showed that they were near solar metallicity in contrast to the RRd stars (renamed to AHB1) that were metal-poor. Sandage and Tammann (2006) discussed these stars further and argued that the AHB1 stars are genuine Population II Cepheids, while the AHB3 stars are their Population I analogs. Based on this, we suggest that V371 Per is an AHB3 star and that it is the first such star known to exhibit double-mode pulsation.

TABLE 1

ATMOSPHERIC PARAMETERS FOR V371 PER

Midexposure HJD 2,450,000 (1)	$V - R$ (2)	T_{eff} (3)	log g (4)	[Fe/H] (5)	E_{V-R} (6)
4838.67	0.381	6208	2.56	–0.01	0.109
4839.69	0.387	6250	1.83	–0.10	0.136
4840.75	0.357	6410	2.91	–0.04	0.108
4841.79	0.447	6166	1.38	–0.05	0.193
Mean	0.397	6218	2.17	–0.05	0.136
Std. dev.	...	166	0.69	0.04	0.040

To compare V371 Per to theoretical models, we will assume it has a mass in the range from 0.50 to 0.65 $M_{\odot}$, as befits a type II Cepheid. There is some uncertainty in determining the luminosity, since published period-luminosity relations may not strictly apply to the AHB3 stars. However, as a first estimate we calculate $M_V = -0.6$ from the Population II Cepheid period luminosity of Sandage and Tammann (2006). Applying a bolometric correction interpolated from the tables of VandenBerg & Clem (2003) with the stellar parameters in Table 1, we obtain $\log(L/L_{\odot}) = 2.1$.

Di Criscienzo et al. (2007) published a series of models covering an appropriate mass regime, but they did not include metallicities as high as our measured value for V371 Per. Although that article does not give detailed information on the period ratio, it indicates that $\log P_{FO} \sim \log P_F - 0.12$ or $P_F/P_{FO} \sim 0.76$. An increase in metallicity decreases the period ratio in the classical Cepheid models of Buchler & Szabó (2007) and Buchler (2008). If the same is true at low masses, there may be models near solar metallicity that reproduce the period ratio of V371 Per. However, these calculations indicate that stable pulsation in the first overtone does not occur at luminosities as high as $\log(L/L_{\odot}) = 2.1$. Whether the use of solar metallicity would alleviate this problem is uncertain.

Bono et al. (1997) published model calculations intended to represent solar metallicity RR Lyrae stars. The period ratios are about 0.713 for the most luminous model, $\log(L/L_{\odot}) = 1.81$, and tend to decrease with increasing luminosity; it appears that these models would not reproduce the period ratio of V371 Per if extended to its luminosity. Additionally, they too lack overtone pulsation at the luminosity of V371 Per.

Buchler & Moskalik (1992) (updated with Livermore opacities in Buchler & Buchler 1994) calculated models with a range of parameters appropriate to the BL Her stars, including some with solar metallicity and $\log(L/L_{\odot}) = 2.1$. However, they were largely concerned with the effect of resonances on light and radial velocity curves and did not provide extensive results relating to the first overtone mode. They did comment, in contradiction to the studies discussed in the previous paragraphs, that “over most of the studied range of T_{eff}, the first overtone is unstable.” The only period ratios that can be extracted from this article (by comparing their Figs. 3 and 14) are for low-metallicity models with $\log(L/L_{\odot}) = 2.0$. The ratios fall in the range of $P_F/P_{FO} \sim 0.713$–0.731. While the largest value does agree with that for V371 Per, it is difficult to know how this would be affected by extrapolation to solar metallicity. Again, a firm conclusion is elusive.

Given that the existing pulsational models do not pertain to the observational parameters of V371 Per, any comparison of theory with observation is very uncertain. More appropriate models would be extremely useful for understanding the nature of this star. In particular, it would be helpful to know whether such models reproduce the observed period ratios and whether double-mode pulsation can occur at the solar metallicity, low-mass, observed temperature, and inferred luminosity of V371 Per. This could also serve to clarify the properties of the AHB3 stars and to help place them in the evolutionary picture for old Population I stars. It is hoped that such models will become available to help understand this very unusual star.

Maas et al. (2007) derived elemental abundances for 19 type II Cepheids from high-resolution spectra. The C, N, and O abundances showed evidence of contamination by the products of the triple-α process and CN cycling in both short-period (BL Her) and long-period (W Vir) stars. However, in the BL Her stars, sodium was significantly overabundant, while the W Vir stars had normal sodium abundance. Maas et al. (2007) suggested that this was due to two different evolutionary paths predominantly populating the lower- and higher-luminosity (i.e. the short-period and long-period) portions of the instability strip. They attributed this dichotomy to differences in the effects of mass loss that affected where individual stars subsequently settled on the blue horizontal branch (BHB). They then proposed that the location on the BHB determines how long a star spends in the instability strip after leaving the BHB and hence whether it was likely to be observed as a variable. Thus, with a larger sample we would expect a small number, perhaps 10%, of stars to deviate from this abundance pattern. Clearly, a detailed abundance study of V371 Per would be very useful to place it in this scenario. A pulsational mass determined from the double-mode pulsation could then give further support to this evolutionary hypothesis. It is hoped that such an analysis will be conducted for this object.

The author is grateful to the staff members of Kitt Peak National Observatory for their assistance in obtaining the data used here. Danielle Rogalla and Lauren Thacker-Lynn assisted with obtaining the observations, and their help is gratefully acknowledged. The University of Nebaraska Research Council and the University of Nebraska Undergraduate Creative Activities and Research Program provided travel funds. Insights into pulsational models for double-mode type II Cepheids provided by Marcella Marconi are much appreciated.

REFERENCES

Bono, G., Caputo, F., Cassisi, S., Incerpi, R., & Marconi, M. 1997, ApJ, 483, 811
Buchler, J. R. 2008, ApJ, 680, 1412
Buchler, J. R., & Buchler, N. E. G. 1994, A&A, 285, 213
Buchler, J. R., & Moskalik, P. 1992, ApJ, 391, 736
Buchler, J. R., & Szabó, R. 2007, ApJ, 660, 723
Di Criscienzo, M., Caputo, F., Marconi, M., & Cassisi, S. 2007, A&A, 471, 893
Diethelm, R. 1983, A&A, 124, 108
———. 1990, A&A, 239, 186
Harris, H. C. 1981, AJ, 86, 719
Maas, T., Giridhar, S., & Lambert, D. L. 2007, ApJ, 666, 378
McCall, M. L. 2004, AJ, 128, 2144
Sandage, A., & Tammann, G. A. 2006, ARA&A, 46, 93
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Schmidt, E. G., Chab, J. R., & Reiswig, D. E. 1995, AJ, 109, 1239
Schmidt, E. G., Rogalla, D., & Thacker-Lynn, L. 2011, AJ, (in press)
Sziládi, K., Vkinkó, J., Poretti, E., Szabados, L., & Kun, M. 2007, A&A, 473, 579
VandenBerg, D. A., & Clem, J. L. 2003, ApJ, 126, 778
Wils, P., Henden, A. A., Kleidis, S., Schmidt, E. G., & Welch, D. L. 2010, MNRAS, 402, 1156